Fig. 1

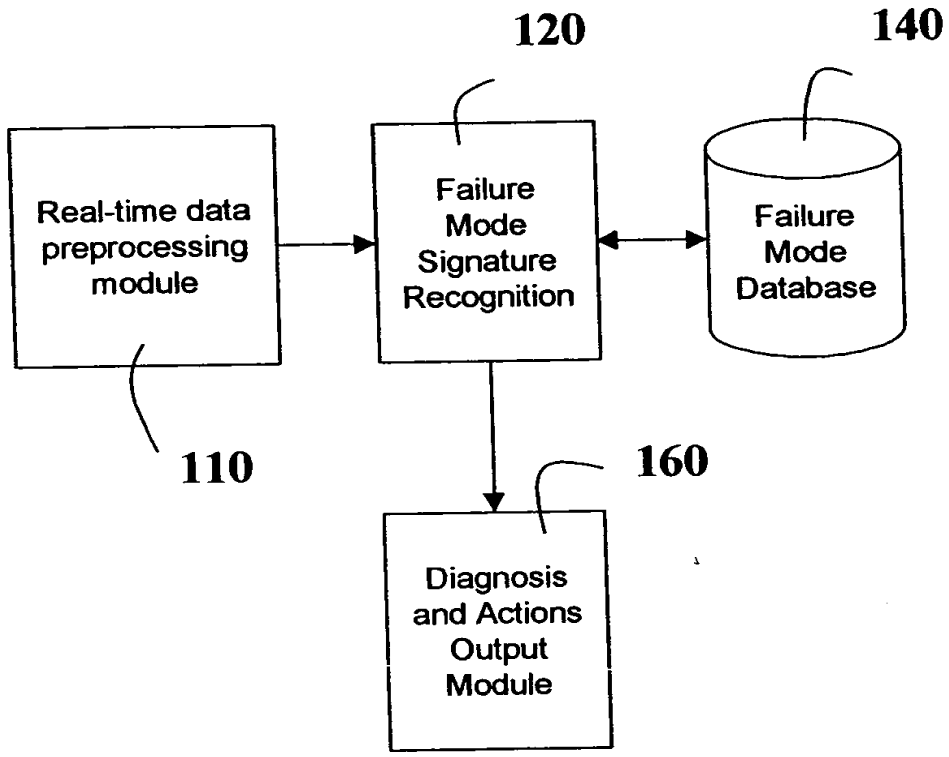

120
140
Real-time data preprocessing module
Failure Mode Signature Recognition
Failure Mode Database
110
160
Diagnosis and Actions Output Module

Fig. 2

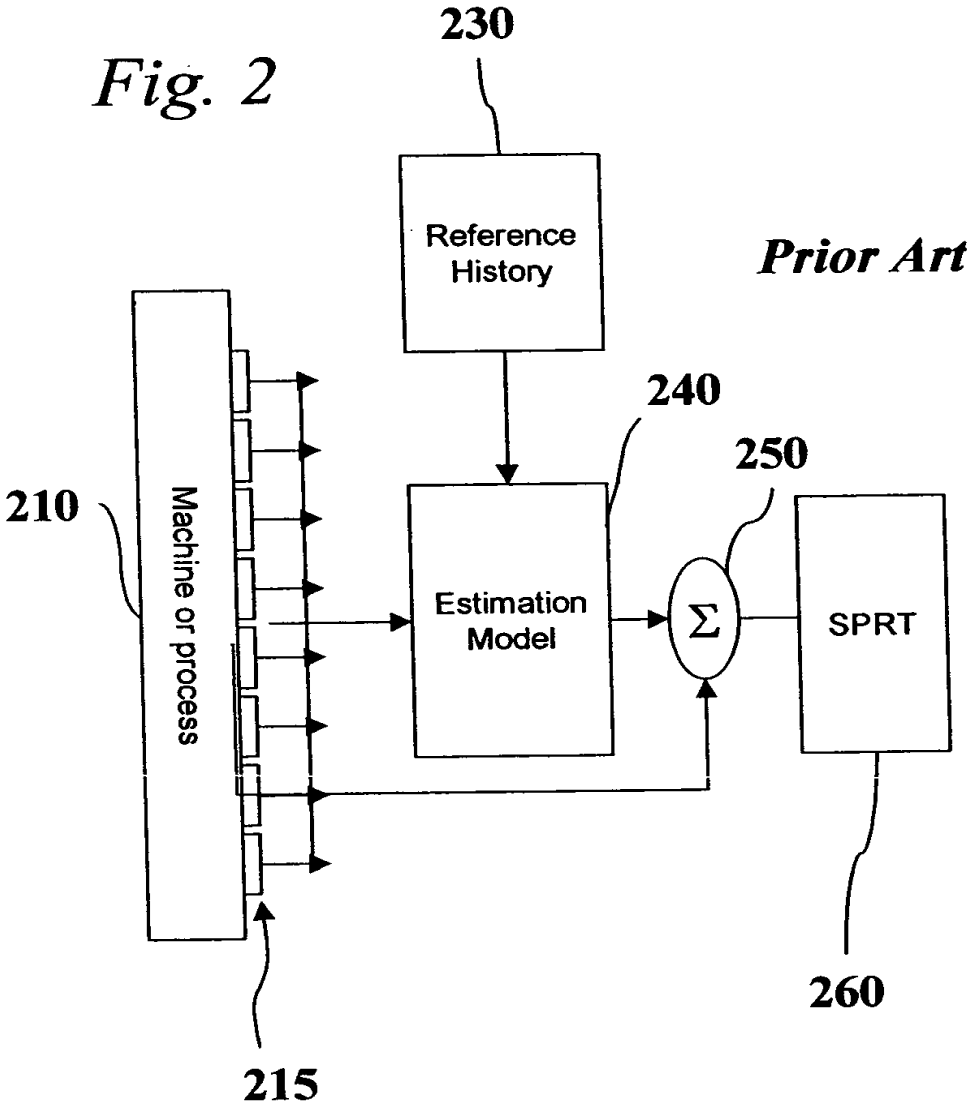

230
Reference History
Prior Art
240
250
210
Machine or process
Estimation Model
Σ
SPRT
260
215

Fig. 3

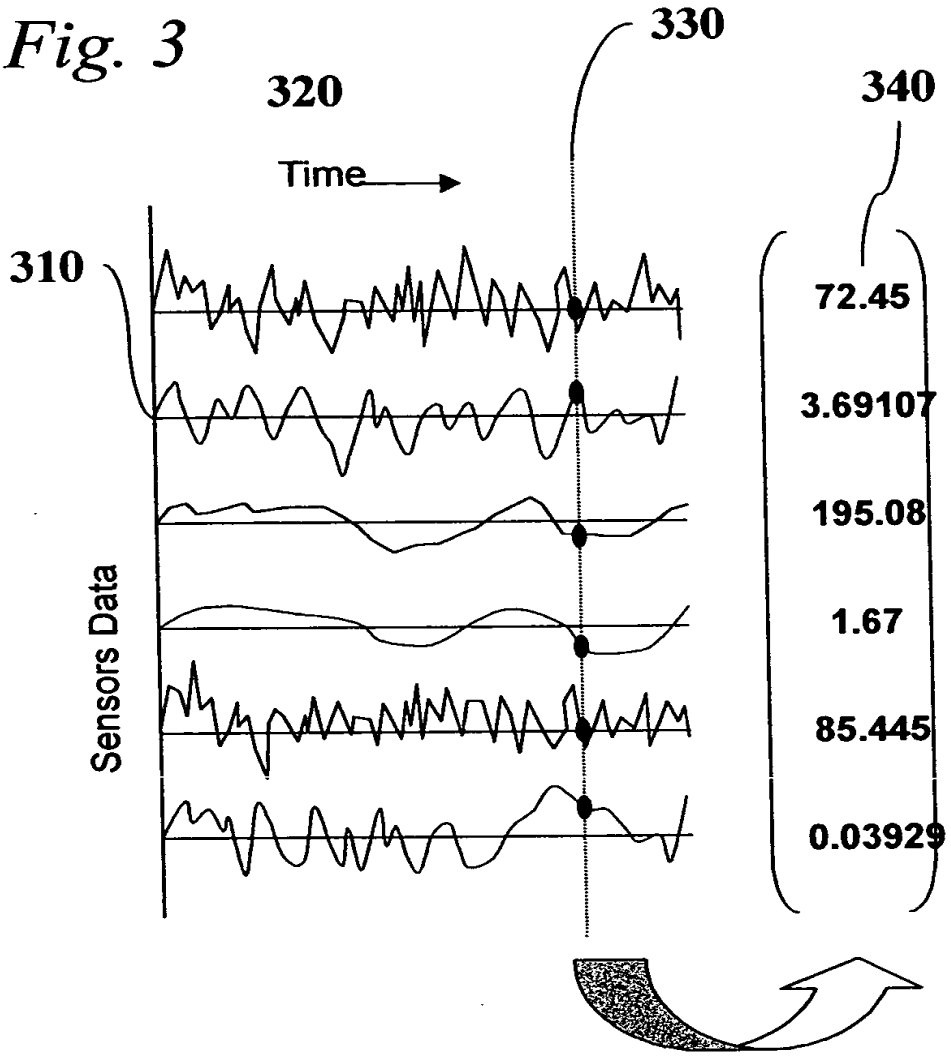
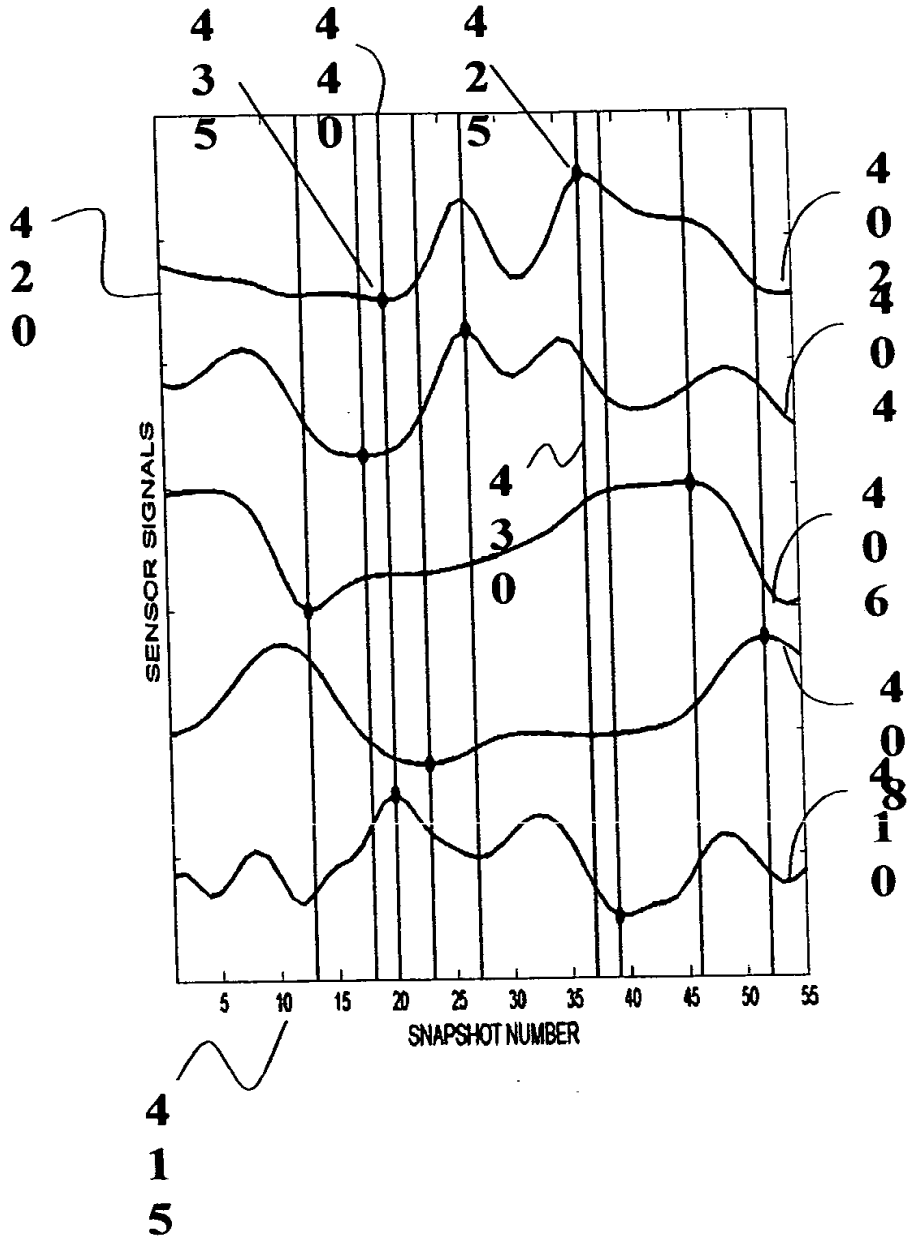

330
320
340
Time
310
72.45
3.69107
195.08
1.67
85.445
0.03929
Sensors Data

Fig. 4


435
440
425
420
402
404
430
406
408
410
415
SENSOR SIGNALS
5
10
15
20
25
30
35
40
45
50
55
SNAPSHOT NUMBER

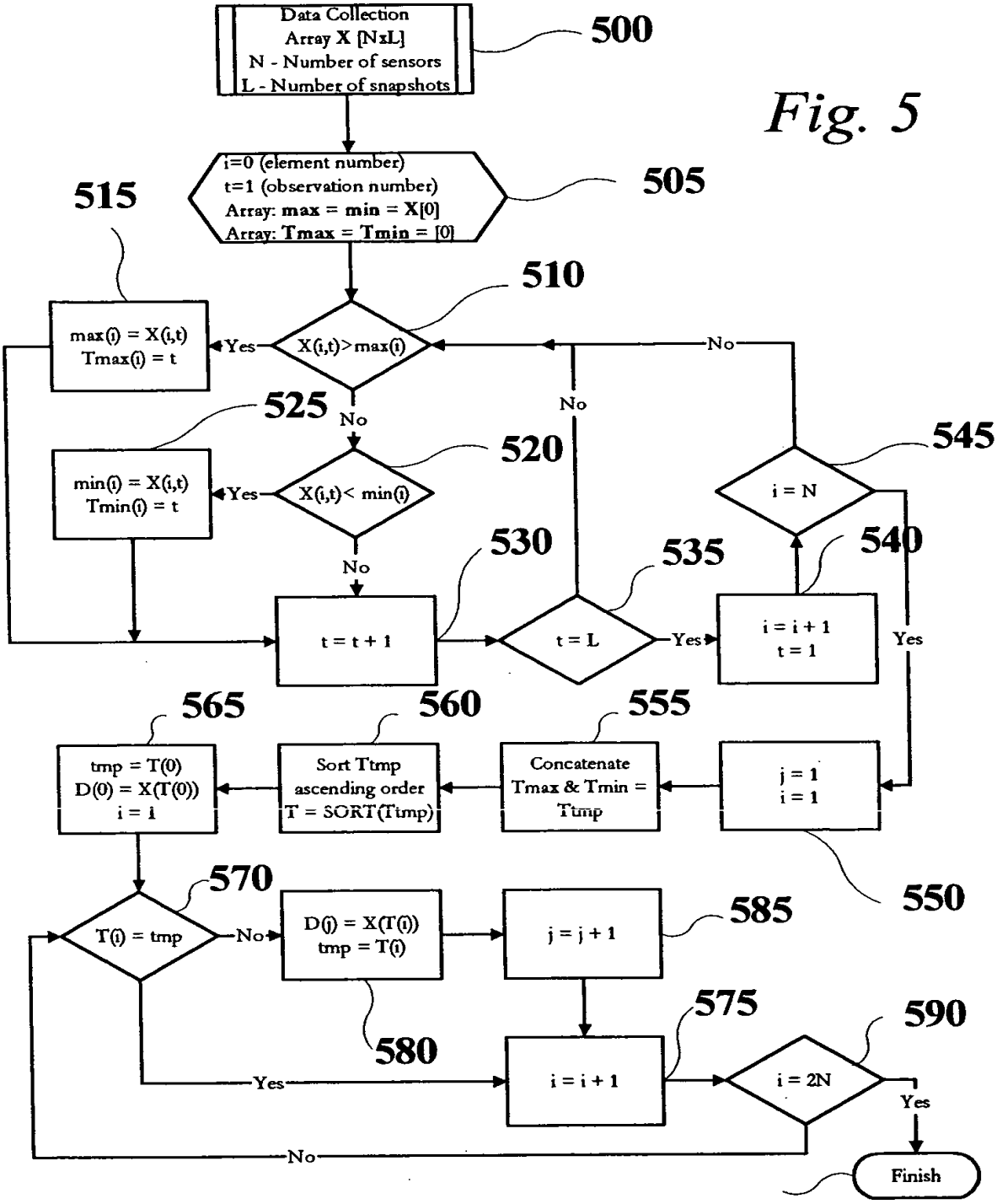
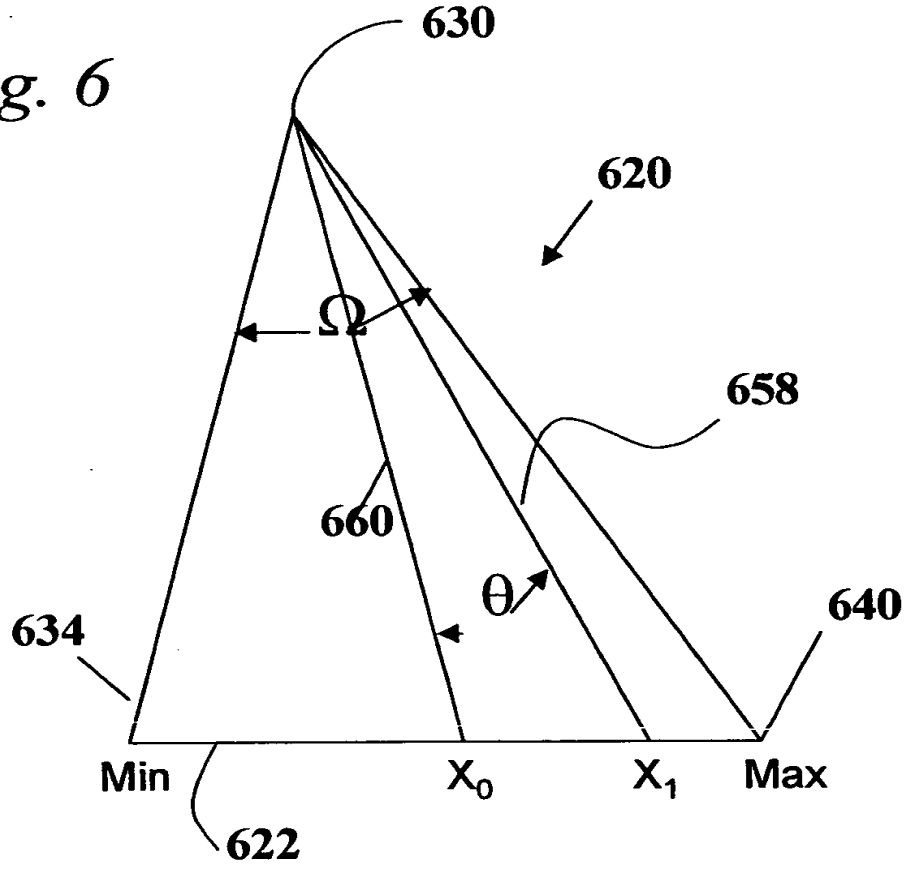

Data Collection
Array X [NxL]
N - Number of sensors
L - Number of snapshots
500
i=0 (element number)
t=1 (observation number)
Array: max = min = X[0]
Array: Tmax = Tmin = [0]
505
515
max(i) = X(i,t)
Tmax(i) = t
Yes
X(i,t)>max(i)
510
No
No
525
No
min(i) = X(i,t)
Tmin(i) = t
Yes
X(i,t)< min(i)
520
545
i = N
No
530
535
540
t = t + 1
t = L
Yes
i = i + 1
t = 1
Yes
565
560
555
tmp = T(0)
D(0) = X(T(0))
i = i
Sort Ttmp
ascending order
T = SORT(Ttmp)
Concatenate
Tmax & Tmin =
Ttmp
j = 1
i = 1
550
570
T(i) = tmp
No
D(j) = X(T(i))
tmp = T(i)
j = j + 1
585
580
575
590
Yes
i = i + 1
i = 2N
Yes
No
Finish

Fig. 5

Fig. 6



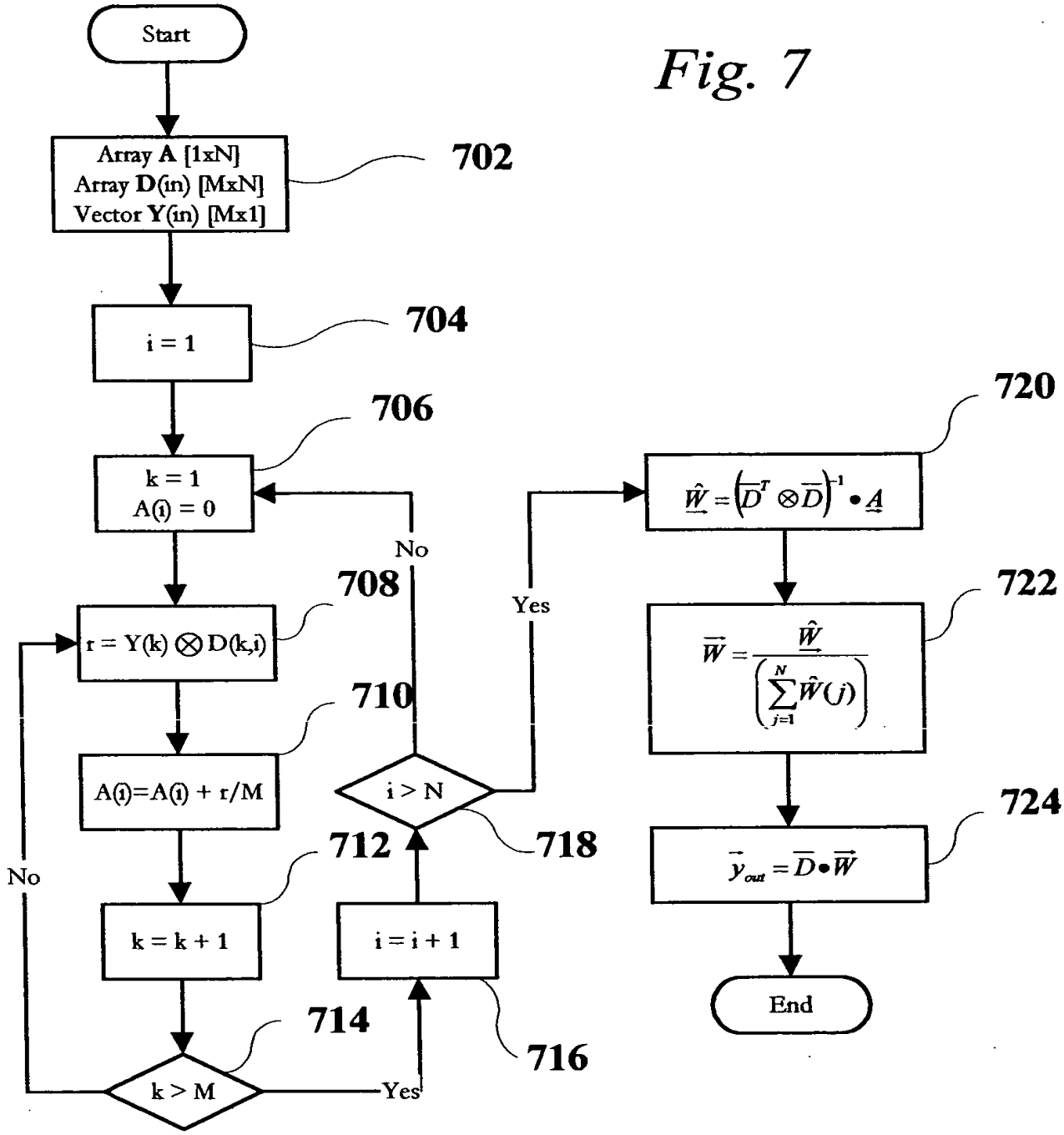

Start
Array A [1xN]
Array D(in) [MxN]
Vector Y(in) [Mx1]
702
i = 1
704
k = 1
A(i) = 0
706
r = Y(k) ⊗ D(k,i)
708
A(i)=A(i) + r/M
710
k = k + 1
712
k > M
714
No
Yes
i = i + 1
716
i > N
718
No
Yes
$\hat{W} = \left(D^T \otimes D\right)^{-1} \bullet A$
720
$W = \frac{\hat{W}}{\left(\sum_{j=1}^{N} \hat{W}(j)\right)}$
722
$y_{out} = D \bullet W$
724
End

Fig. 7

Fig. 8A

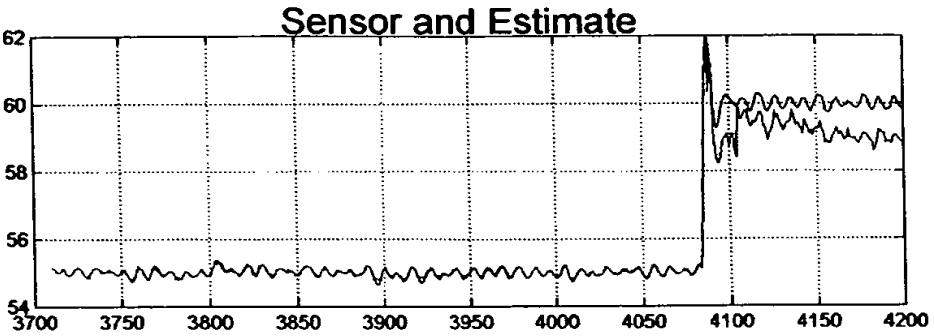


Fig. 8B

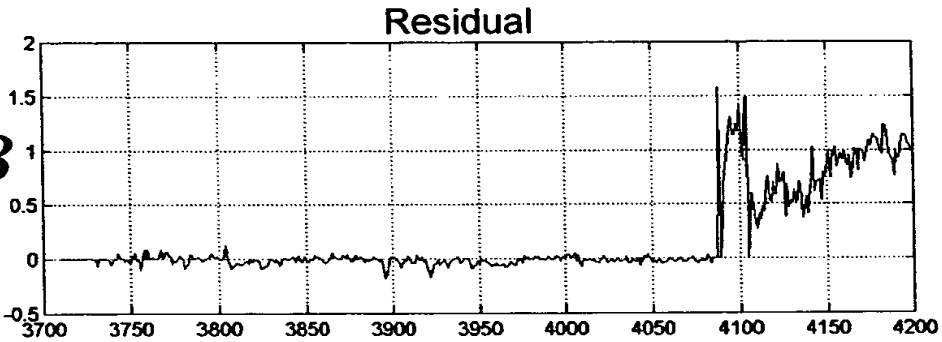


Fig. 8C

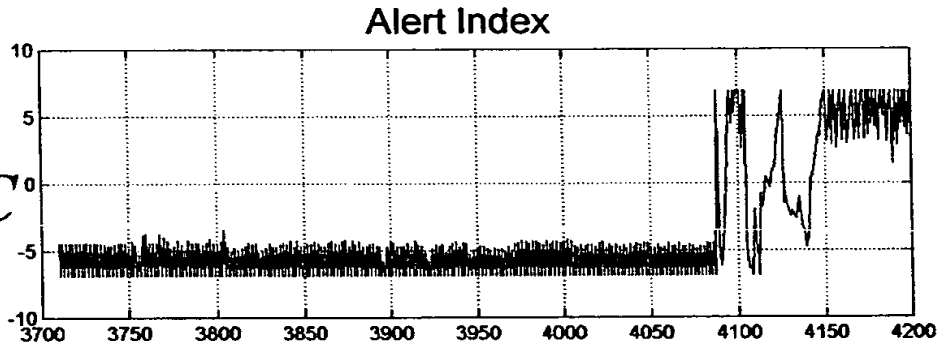
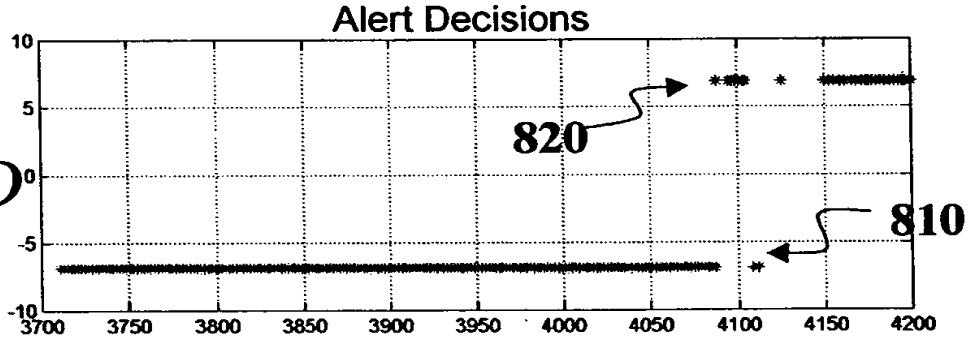


Fig. 8D



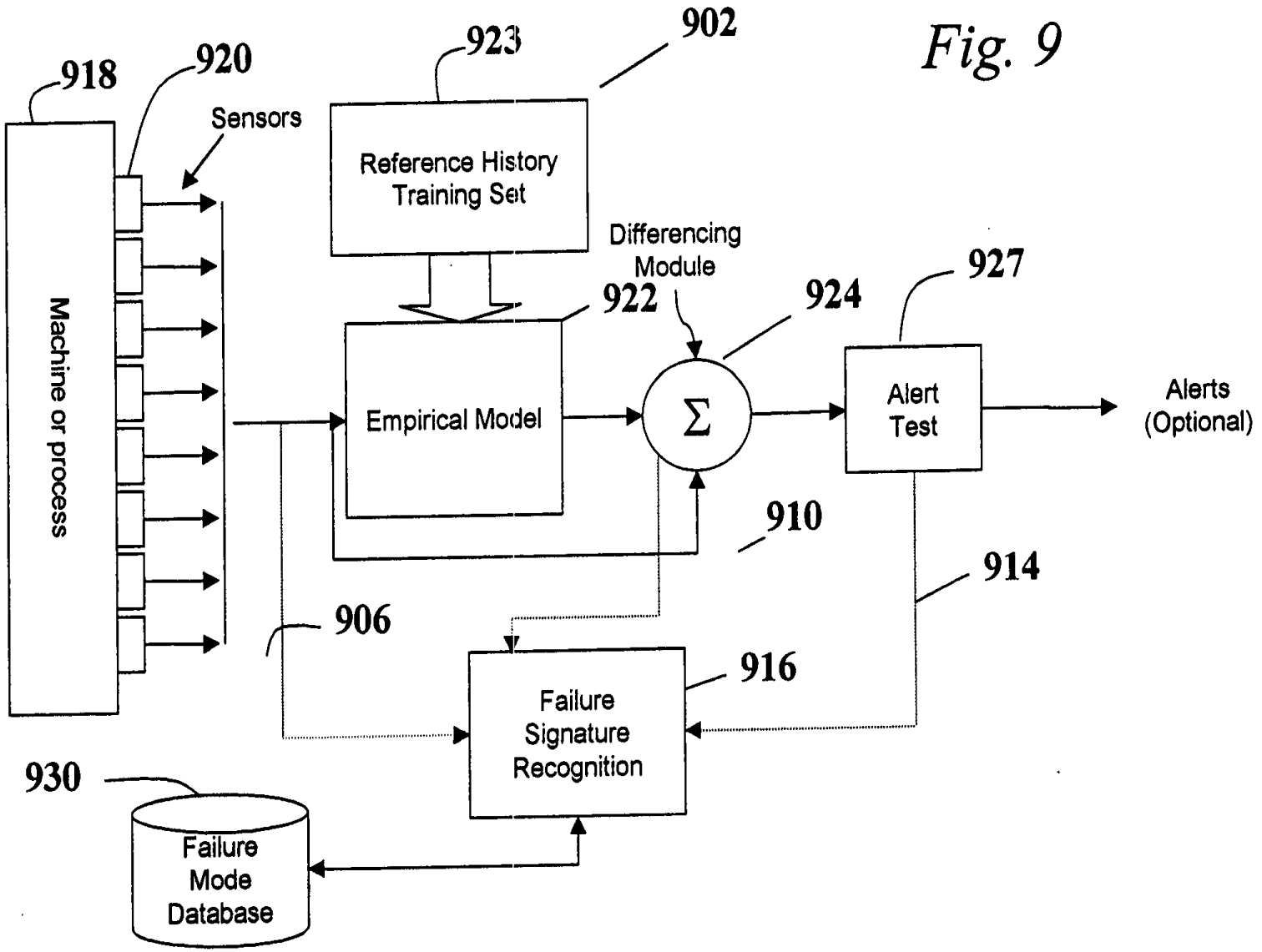


Fig. 9
902
923
918
920
Sensors
Reference History
Training Set
Differencing
Module
922
924
927
Machine or process
Empirical Model
Σ
Alert
Test
Alerts
(Optional)
910
914
906
916
Failure
Signature
Recognition
930
Failure
Mode
Database

Fig. 10

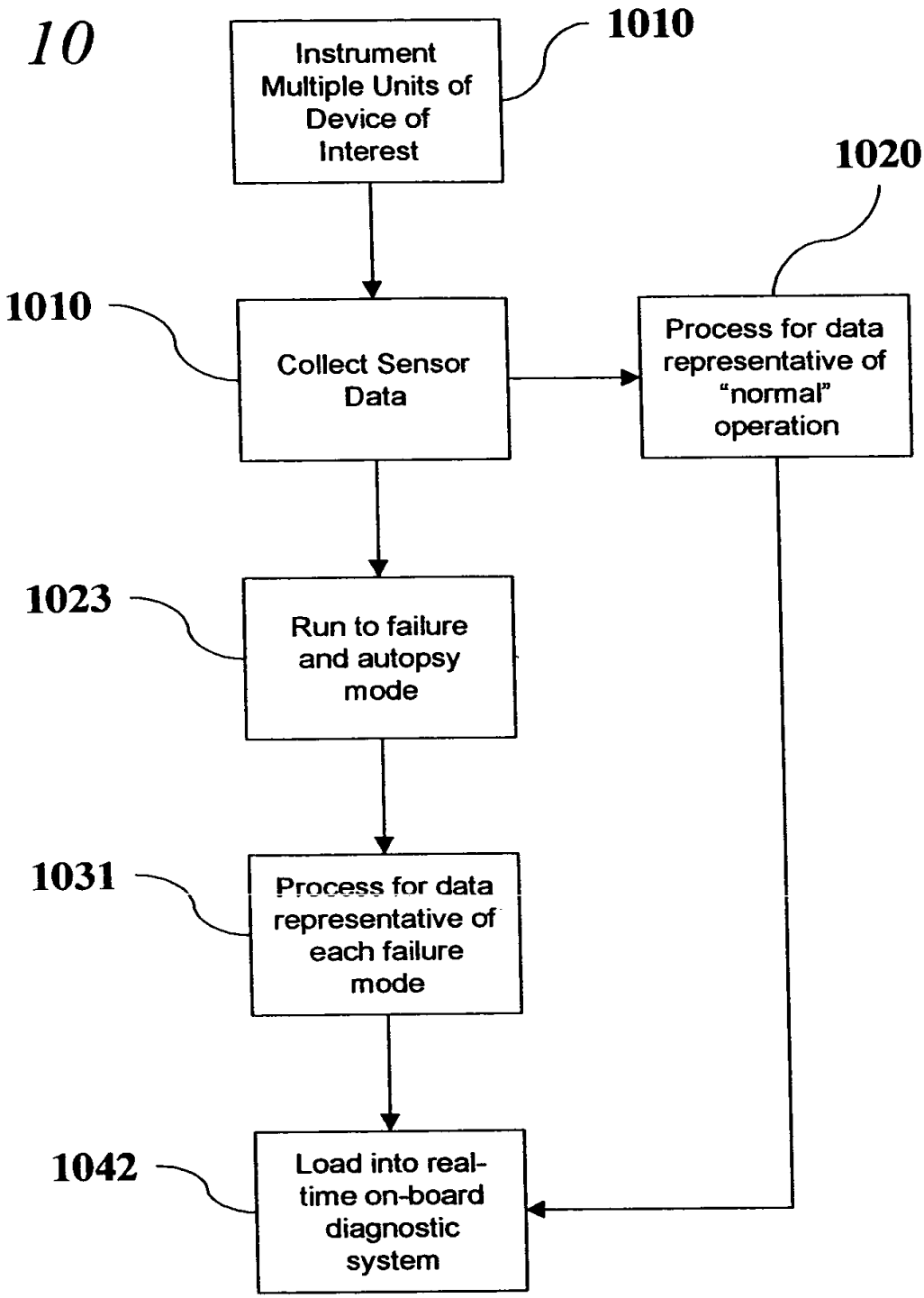

Instrument Multiple Units of Device of Interest
1010
1020
1010
Collect Sensor Data
Process for data representative of "normal" operation
1023
Run to failure and autopsy mode
1031
Process for data representative of each failure mode
1042
Load into real-time on-board diagnostic system

Fig. 11

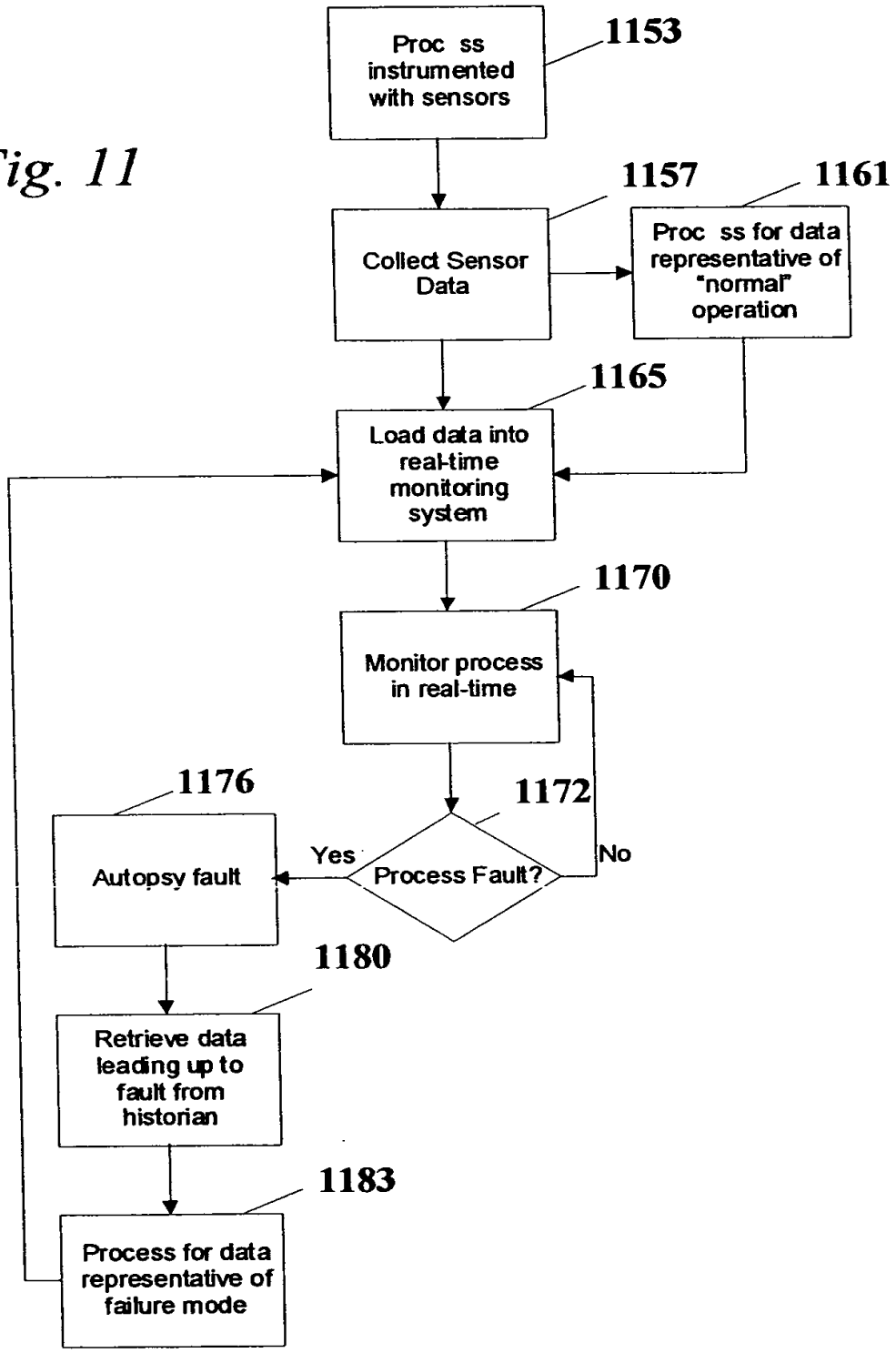

Proc ss instrumented with sensors
1153
Collect Sensor Data
1157
Proc ss for data representative of "normal" operation
1161
Load data into real-time monitoring system
1165
Monitor process in real-time
1170
Process Fault?
1172
Yes
No
Autopsy fault
1176
Retrieve data leading up to fault from historian
1180
Process for data representative of failure mode
1183

Fig. 12A

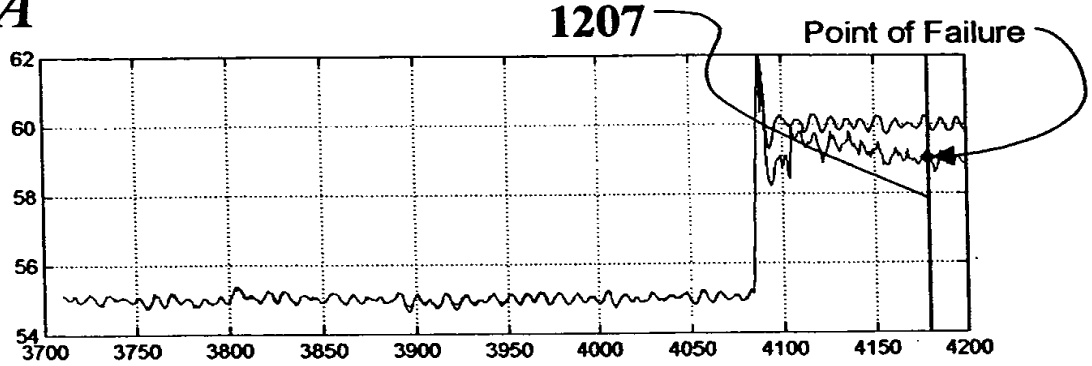


Fig. 12B

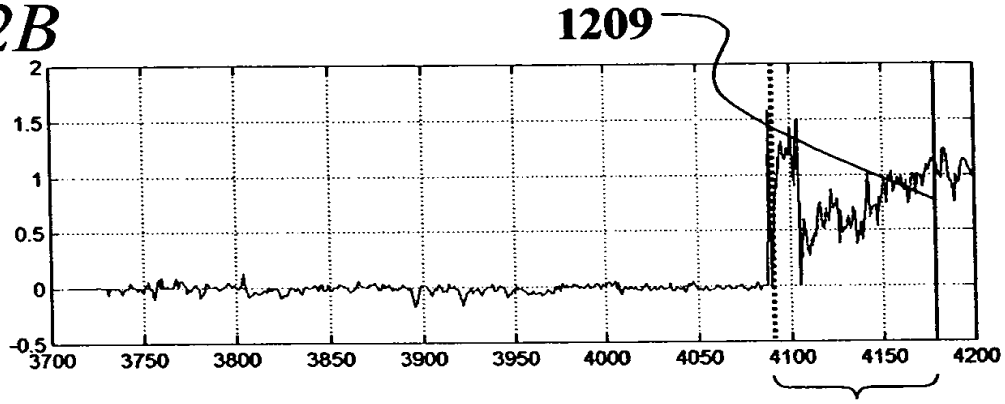


Fig. 12C

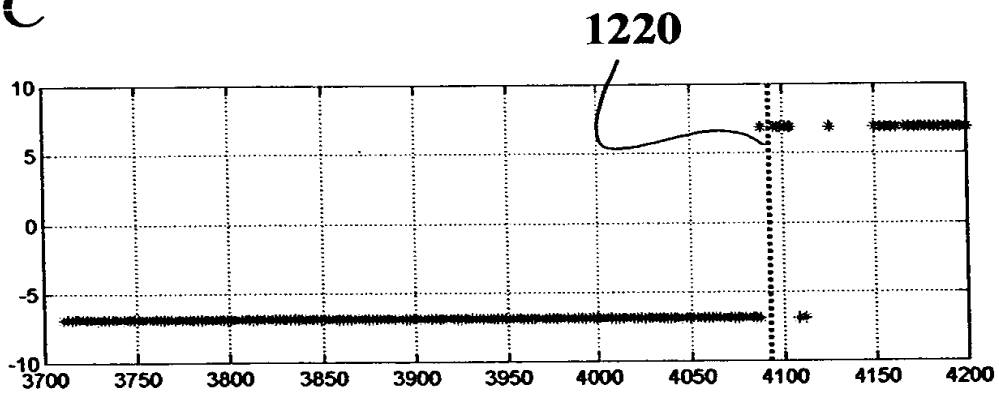
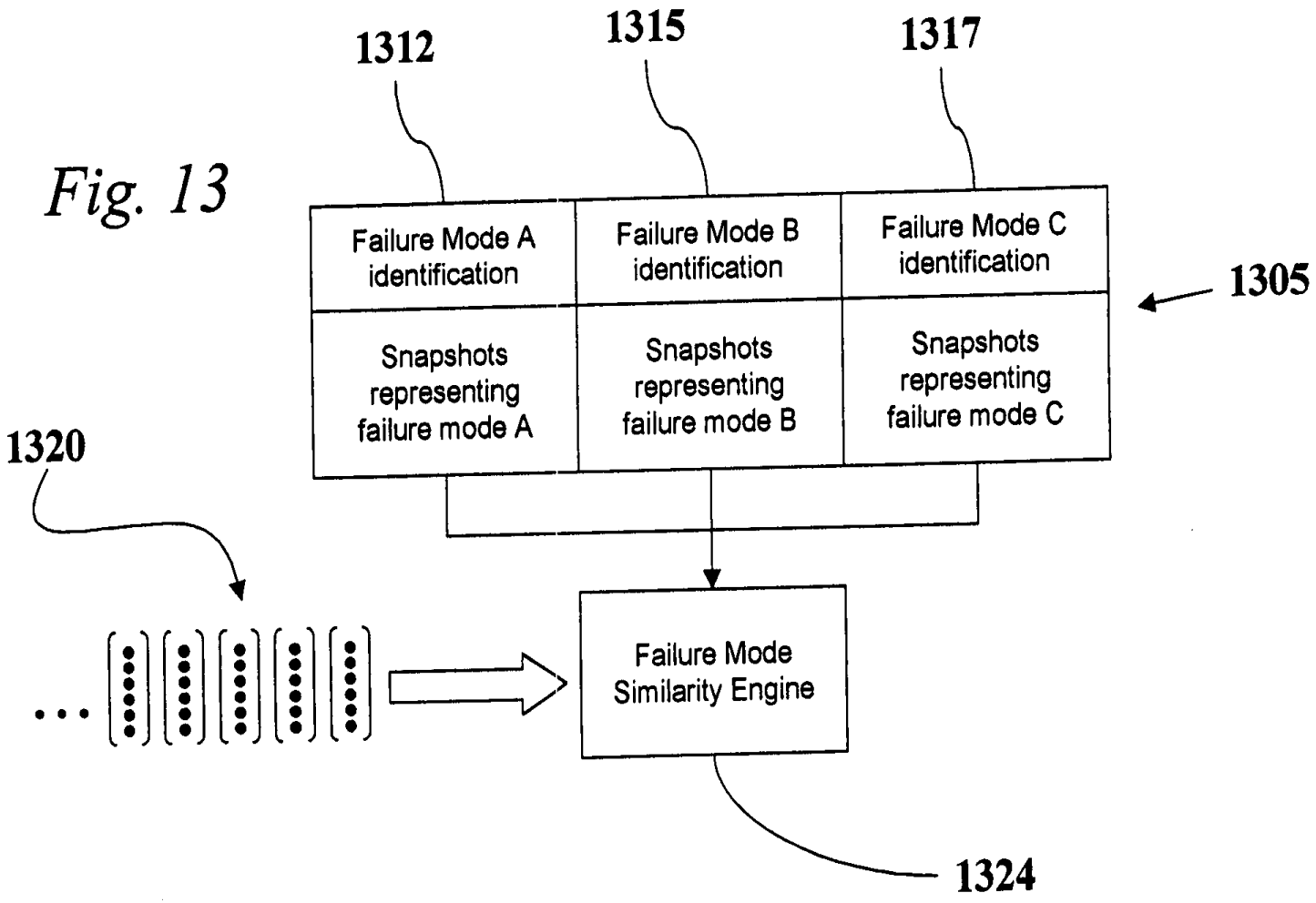


Fig. 13


1312
1315
1317
Failure Mode A identification
Failure Mode B identification
Failure Mode C identification
Snapshots representing failure mode A
Snapshots representing failure mode B
Snapshots representing failure mode C
1305
1320
Failure Mode Similarity Engine
1324

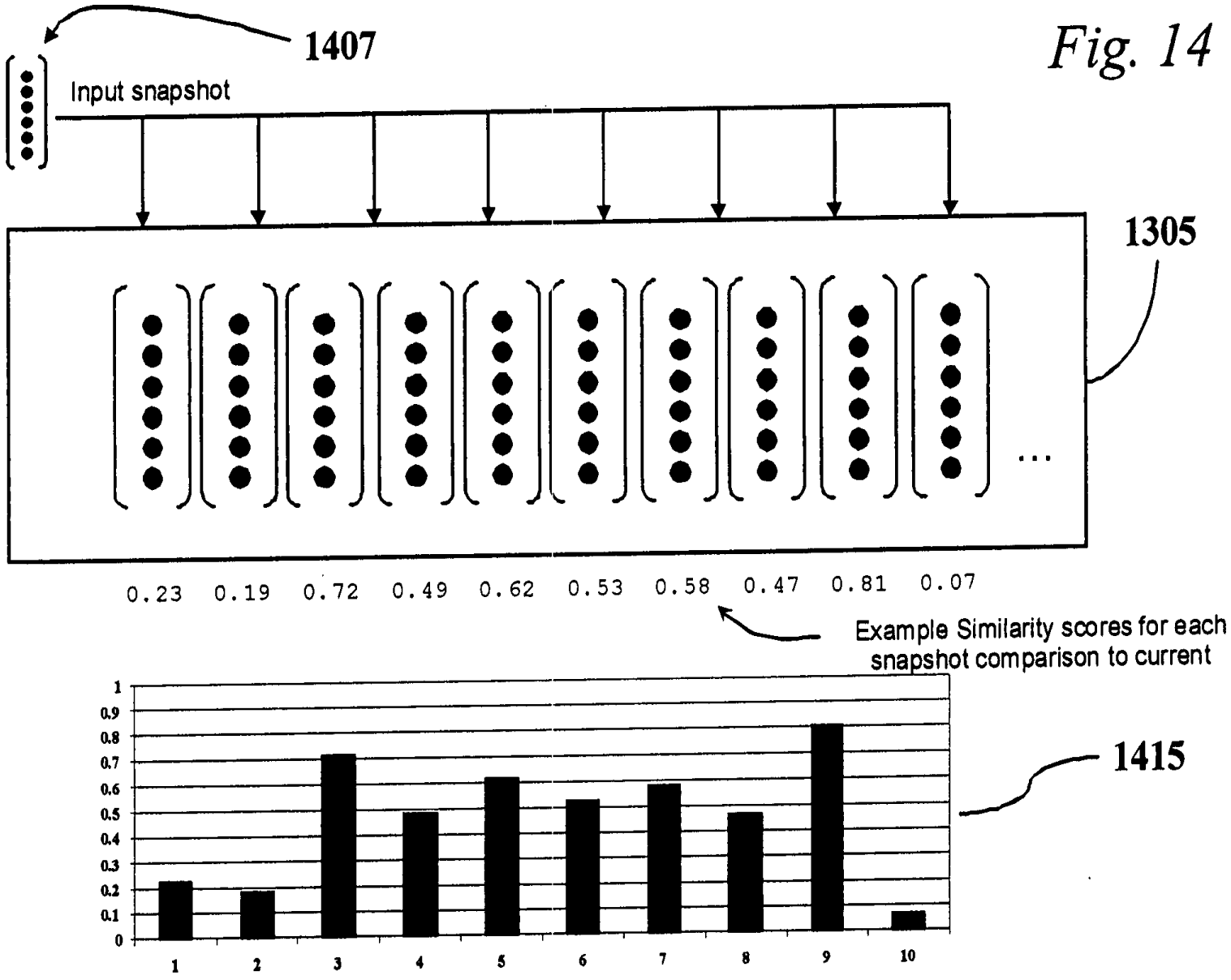

1407
Input snapshot
1305
0.23 0.19 0.72 0.49 0.62 0.53 0.58 0.47 0.81 0.07
Example Similarity scores for each snapshot comparison to current
1415
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 2 3 4 5 6 7 8 9 10

Fig. 14

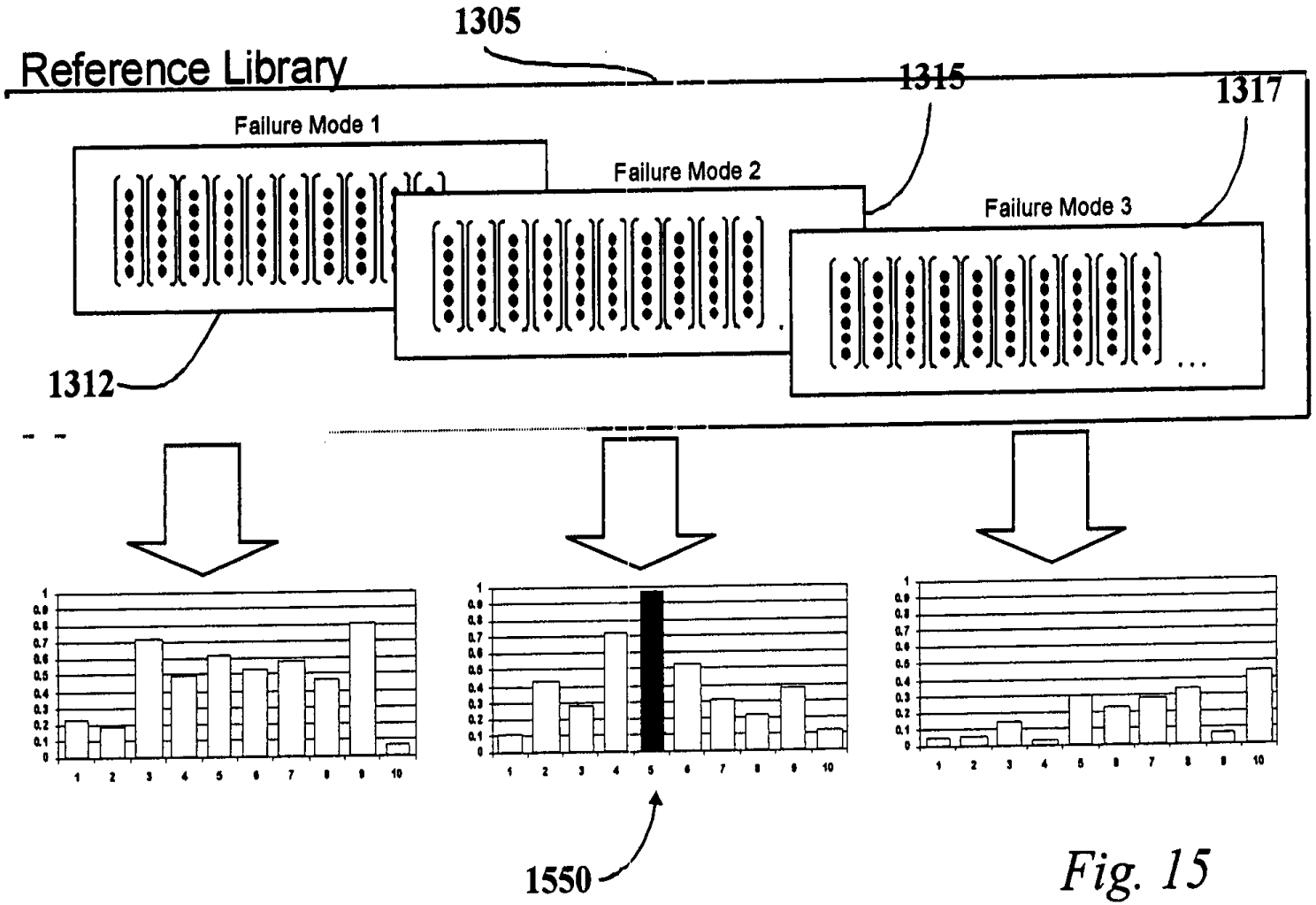
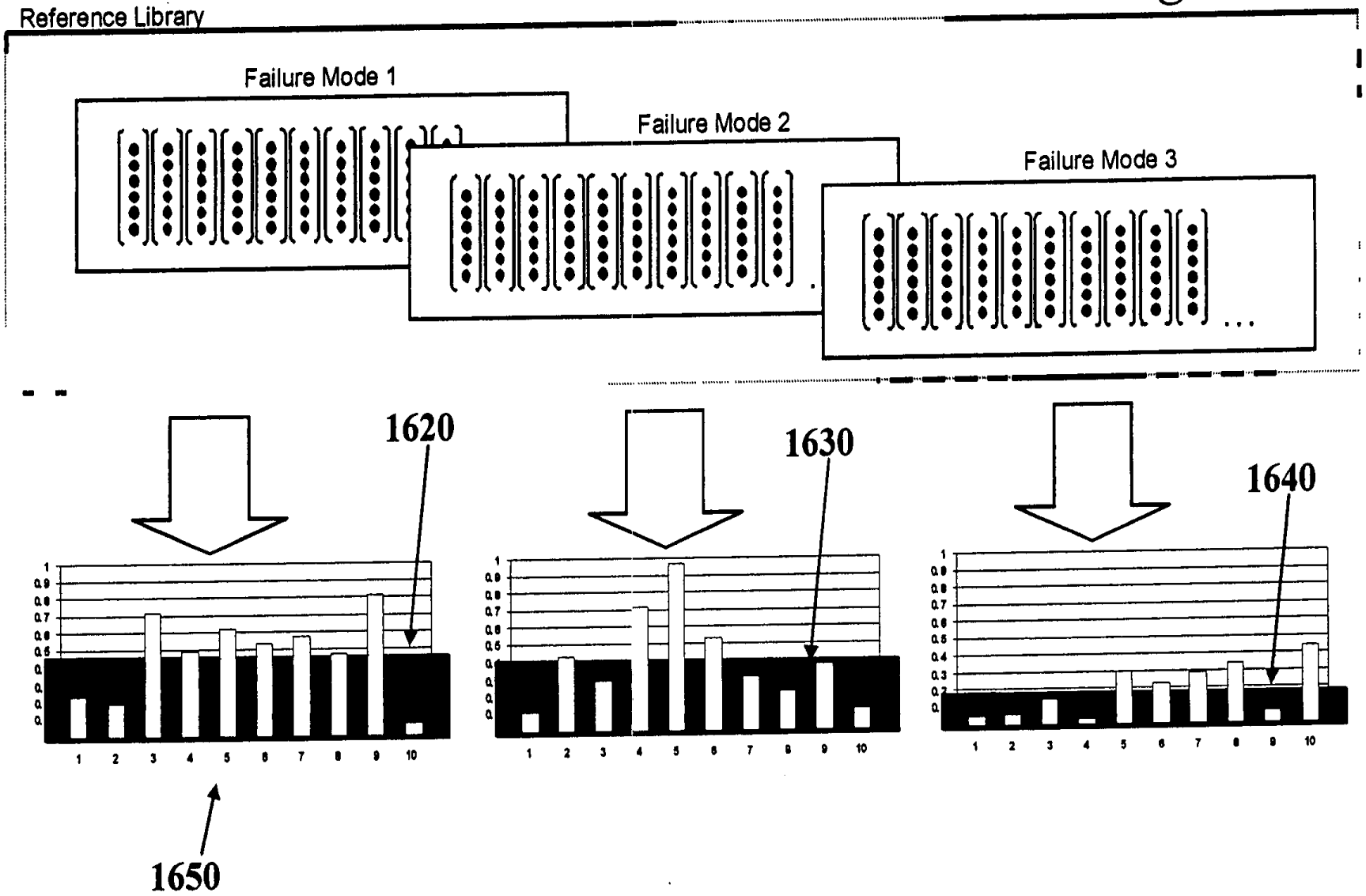

1305
Reference Library
1315
1317
Failure Mode 1
Failure Mode 2
Failure Mode 3
1312
1550

Fig. 15

Fig. 16


Reference Library
Failure Mode 1
Failure Mode 2
Failure Mode 3
1620
1630
1640
1650

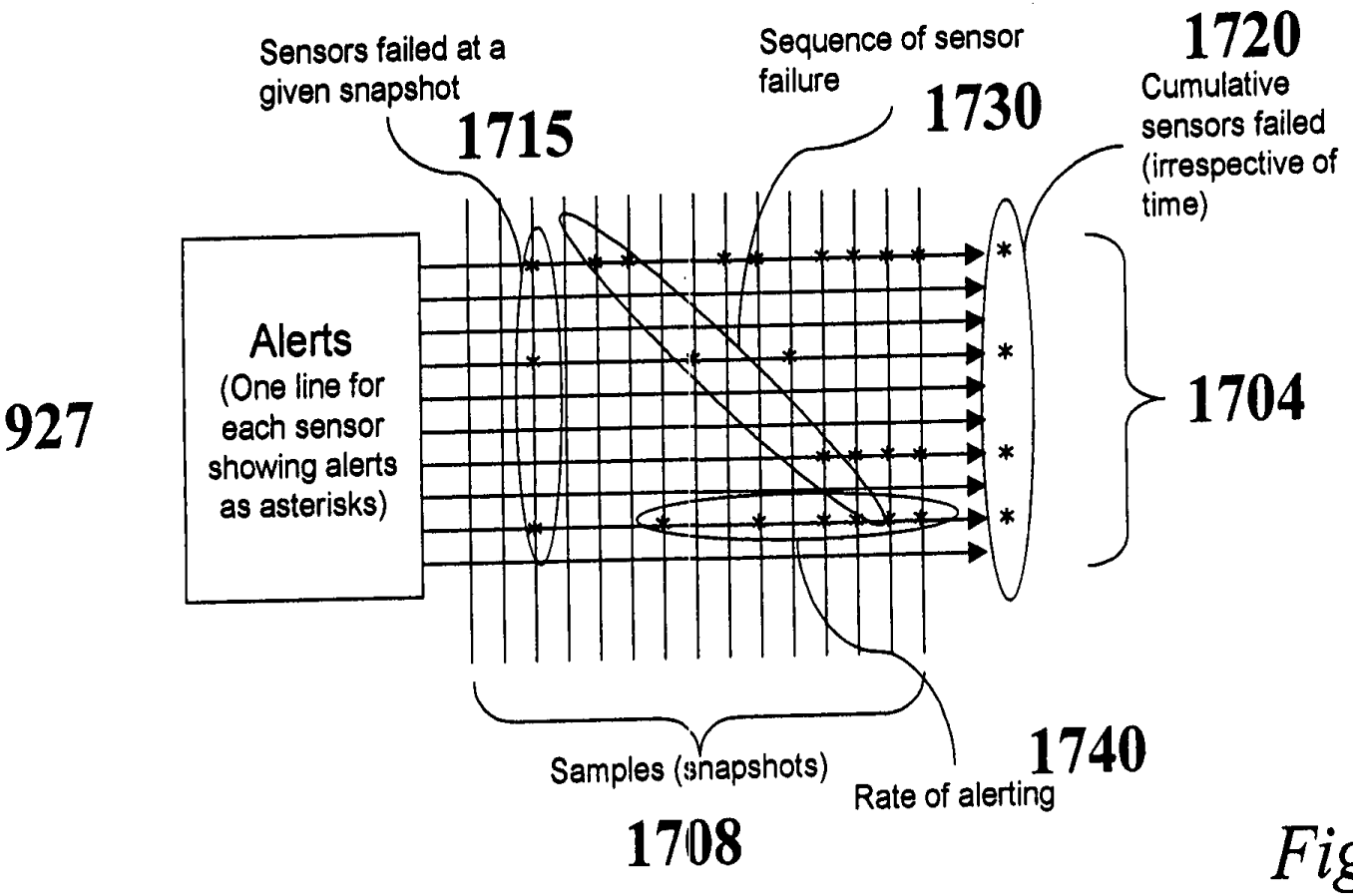
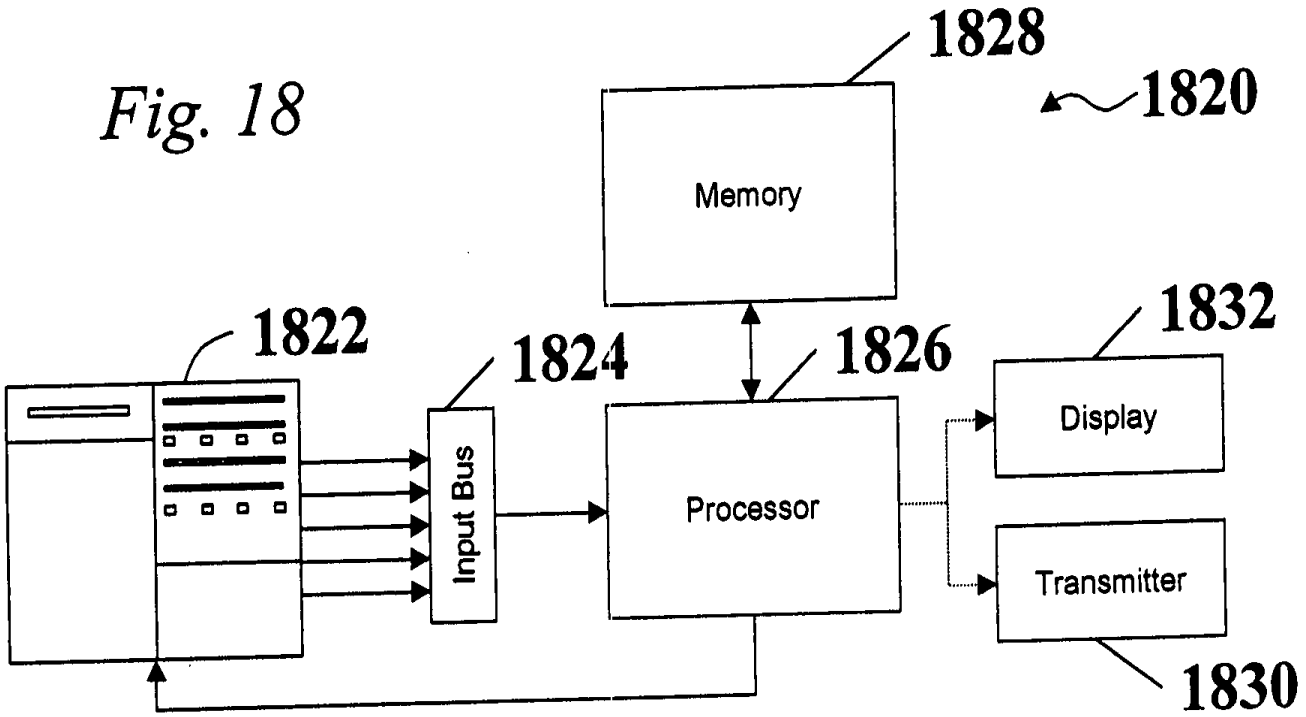

Sensors failed at a given snapshot
1715
Sequence of sensor failure
1730
1720
Cumulative sensors failed (irrespective of time)
Alerts
(One line for each sensor showing alerts as asterisks)
927
1704
Samples (snapshots)
1708
Rate of alerting
1740

Fig. 17

Fig. 18


1828
1820
Memory
1822
1824
1826
1832
Input Bus
Processor
Display
Transmitter
1830